CAKALELE, VOL. 9 (1998): 3–15

Hydrographic Influences on Zooplankton Biodiversity around Pulau Ambon, Maluku

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1. Introduction

The adoption of Agenda 21 at the UN 1992 Earth Summit in Rio lays responsibility on all governments to protect global biodiversity, namely, the range of living organisms on the planet. One measure of biodiversity is species richness, the number of species present in an area. Species richness in ocean waters appears to be similar to that in the richer terrestrial communities, but the generally wider distributional limits of the oceanic biota means that the total oceanic species pool is much lower than for terrestrial species (Angel 1994).

Plankton are, generally, microscopic organisms that live in natural waters and that have only limited powers of locomotion, such that they drift with the prevailing currents. Away from coastal areas, the plant plankton (phytoplankton) form the base of the food chain. The animal component, the zooplankton, play an important role, transferring production from the plants to higher organisms such as fish. They also consume detritus, particles of nonliving organic matter such as fragments of leaves and seaweeds, or fecal pellets, thus making this material available for higher levels of the food chain.

Zooplankton are a diverse group containing representatives of almost every major taxonomic group. Some of these are present in the zooplankton just for short periods, as is the case with the larval stages of some fish (Wickstead 1965, Tait 1972, Parsons et al. 1977, Newell and Newell 1977). Many invertebrate species also have larval stages that utilize the plankton (e.g., polychaetes, crustaceans, molluscs and echinoderms).

The most conspicuous element in the permanent plankton (holoplankton) are crustaceans. Commonly, they contribute at least 70% of the total individuals in the zooplankton community, and the predominant class is copepods. The copepods often outnumber all the other animal groups, and are represented by many species. They play an important role in the trophic dynamics of marine ecosystems, being the primary food for many fish species (Dussart 1965, Wickstead 1965, Bougis 1976, Newell and Newell 1977, Parsons et al. 1977).

As zooplankton drift with the currents, they have been used as indicators of the region of origin of the water. Given that they live in intimate contact with the medium, they also respond to changes in the quality of the water and so have been used as biological indicators of pollution.

Zooplankton sampling generally involves some form of sieve to separate the organisms from the water. This may occur either in the form of a net, or a sample of water may be pumped from the sea and then screened over a mesh. In either case, sampling introduces a certain selectivity. Fast-moving forms may avoid the net or pump intake, while fragile forms may be destroyed or damaged beyond identification. However, repeated use of the same sampling methodology does allow spatial and temporal comparisons in the catch to be made.

Pulau Ambon (Fig. 1) rises steeply from the floor of the surrounding sea. The island consists of two regions of high ground separated by a narrow low-lying isthmus. To the northeast lies Baguala Bay. Baguala Bay shelves down to >200m depth at its mouth. Ambon Bay lies to the southwest of the isthmus. It has a more complex topography, with a shallow, <40m, Inner Bay separated by a shallow sill from the Outer Bay. Salinity in the Inner Bay is reduced (typical salinities being 20–25) and it receives considerable inputs of urban wastewater. Both regions receive seasonal inputs of oceanic water during the southeast monsoon (April–November). However, during the rainy season, between May and August, the input of freshwater to Ambon Bay reduces the oceanic influence, especially in the Inner Bay.

This study aims to document the biodiversity of the zooplankton of Ambon and Baguala Bays and to focus on the patterns in biodiversity arising from the hydrography of the area. In Ambon Bay this will focus on the changes between the Inner and the Outer Bays, while in Baguala

Bay the focus will be on the influence of the seasonal upwelling driven by the Southeast Monsoon.

2. Materials and methods

In Ambon Bay, zooplankton samples were taken monthly, in the day-time, from 15 fixed stations (Fig. 1) during the period June–August 1990. The collections were made by towing a Norpac-type net, with a diameter of approximately 45cm and a mesh of 330μm. A flow meter was mounted in the net's mouth.

The net was towed horizontally just below the water surface behind a boat, and the duration of each haul was about 3 minutes, with an average speed of 1–2 knots. At the end of each tow, the net was washed down and the zooplankton organisms were collected in the cod end. These were then transferred to jars and fixed in 4% formaldehyde in seawater.

Baguala Bay samples were collected at approximately monthly intervals during an 8-month sampling period that included both monsoons (January–March and May–September 1993) from 7 stations in the Bay (Fig. 1). Sampling was carried out during the daytime and consisted of four vertical hauls of 200μm-meshed WP2 (UNESCO 1968) zooplankton net with a mouth area of 0.25m^2. As each station has a different water depth, the net was hauled from different depths (Table 1). A flow meter was mounted in the mouth of the net to allow determination of the exact volume of water filtered. The catch was pooled and preserved immediately in 4% formaldehyde in seawater.

In the laboratory, samples were sorted and all large (>20mm) organisms were identified to species and enumerated. Abundances of smaller organisms were estimated from counts of 2.5ml aliquots randomly drawn from the sample diluted to 50ml volume.

3. Results

Ambon Bay

A total of 56 taxa (mostly species) were recorded, with as many as 96,465 individuals per m^3 being reached (Station 6, August 1990). Copepods were the dominant group, accounting for 23 of the 56 taxa and up to 71% of the individuals in a sample.

Species richness, zooplankton, and abundance and species composition (how the individuals were distributed between the species) for all the stations to seaward of the sill were similar in the June samples. However, in July and August the fauna at stations 4, 5, 6, 7, 14, and 15 contained—in addition to the "oceanic" component—elements of the inshore community. These stations were therefore regarded as transitional in character and subsequent analysis distinguished: (i) the Outer Bay, oceanic in character; (ii) the Inner Bay, low salinity, eutrophicated; and (iii) the transition region.

Table 1. Position and the depth of hauling at 7 fixed stations throughout Baguala Bay, Ambon Island.

No.	Station	Position	Depth of Hauling (m)
1	Tanjung Meriam (Tial)	03˚38'15"S 128˚21'10"E	200–0
2	Mid (between Tg.Tial-Tg.Hutumuri)	03˚39'30"S 128˚19'45"E	35–0
3	Tanjung Hutumuri	03˚41'30"S 128˚19'0"E	40–0
4	Toisapu	03˚38'45"S 128˚17'16"E	15–0
5	Batu Gong	03˚37'45"S 128˚16'16"E	12.5–0
6	Natsepa	03˚37'40"S 128˚17'30"E	11–0
7	Tanjung Suli	03˚38'20"S 128˚18'35"E	7–0

Calanus, *Paracalanus*, *Oikopleura*, *Oithona*, *Sagitta*, *Corycaeusi*, Euphausid larvae, Copepod larvae, and fish eggs were abundant at all locations sampled. Some taxa were only recorded in certain areas. For example, *Rhincalanus* only occurred in the transition and outer regions; *Euchaeta*, *Salpa*, *Cereis*, *Thalia*, *Hyperia*, *Centropages*, *Doliolum*, *Lingula*, and *Candacia* were also absent from the Inner Bay, while *Penilia*, *Pleurpis*, Cirripedia, Hydrozoa larvae, fish larvae, *Podon*, Brachyuran larvae, and *Tintinopsis* occurred only in the inner and transition regions. In addition, some species had extremely limited distributions. *Euterpina* (Copepod) was only recorded from stations 4 and 7 (June), station 7 (July), and station 15 (August). Stations 4, 7, and 15 were all in the transition region. *Centropages* displayed a similar pattern. It occurred only at stations 5 and 13 (June); stations 5, 6, and 14 (July); stations 5 and 6

(August). With the exception of station 13 (in the Outer Bay), all of them were also in the transition region. *Labidocera* was not recorded in June, but occurred at stations 6 and 7 in July and at stations 7 and 12 in August. Station 12 was in the outer region, while stations 6 and 7 were in the transition region. Fish larvae were found only at station 1 (in July) and station 3 (in August), and they were not recorded at all in June.

Biodiversity, as indicated by species richness, did not vary significantly between regions (χ^2 = 1.628, P>0.05) being highest in the Outer Bay in June, and in the transition region in July and August (Fig. 2). Multivariate analysis of the distribution of individuals by species using MDS (Clarke & Warwick 1994) also showed the variability in the composition of the community at the transition zone stations. In June, station 4 had a similar community to those in the Inner Bay, while the majority of the transition stations were interspersed with those from the Outer Bay (Fig. 3a). In July and August, the transition stations varied a great deal in their community composition (i.e., they are widely dispersed in the MDS plot; Fig. 3b & c), but generally show greater similarity to the Outer Bay stations. This leads to the conclusion that this region is essentially oceanic in character, but the overspill of plankton-bearing water from the Inner Bay boosts the species list for these stations, increasing diversity but not greatly influencing community structure.

Table 2. The mean number of meroplankton and their percentage contribution to the sample in June, July and August 1990 in each region (Inner, transition and Outer Bay).

REGION	JUNE	JULY	AUGUST
Inner	151	123	1,663
	(6.77%)	(3.24%)	(10.60%)
Transition	124	385	10,172
	(2.22%)	(8.19%)	(34.72%)
Outer	69	76	4,754
	(1. 8%)	(1.44%)	(24.69%)

Meroplankton, the temporary members of the community, comprised fish eggs, fish larvae, and the larvae of brachyurans (crab), echinoderms, gastropod snails, bivalves (clams), polychaete worms, and hydrozoans (corals and anemones). The proportion of meroplankton varied spatially and temporally, being highest in August in the transition region (Table 2).

Comparing the combined data for each region, it can be seen that the species composition of zooplankton was most similar for the Outer and transition regions on all sampling occasions, with the Inner and Outer Bay's fauna being least similar (Table 3).

Table 3. The degree of similarity (Bray-Curtis Similarity Index) of each region (Inner, transition, and Outer Bay) in June, July, and August 1990.

SAMPLING PERIOD	REGION	TRANSITION	OUTER
June	Inner	0.77	0.70
	Trans.	-	0.88
July	Inner	0.65	0.62
	Trans.	-	0.79
August	Inner	0.67	0.65
	Trans.	-	0.87

Baguala Bay

During the period January to September 1993, a total of 98 zooplankton taxa, mostly species, were recorded from Baguala Bay. The zooplankton community was dominated by copepods, chaetognaths, crustaceans, appendicularians and medusae. Calanoid copepods of the species *Paracalanus aculeatus*, *Pseudocalanus* sp., *Acrocalanus gracilis, A. longicornis*, *Acartia danae*, *A. amboinensis,* and *A. negligens* were dominant throughout the period of sampling.

The following copepod taxa were only represented by a small number of specimens at certain months and/or stations: *Eucalanus* spp., *Clausocalanus furcatus*, *Canthocalanus pauper, Centropages* spp., *Canadacia* spp., *Pleuromamma* spp., *Temora* spp., *Euchaeta* spp., and *Tortanus* spp. *Eucalanus* spp. were only recorded at stations in the mouth of the Bay (stations A, B, and C). The upwelling indicator copepod, *Rhincalanus nasutus,* was also only recorded at stations in the mouth of the Bay and only from March to October.

4. Discussion

This study has briefly described the zooplankton of two bays at Pulau Ambon. Both of them benefit from inputs of nutrient-rich deep water during the Southeast Monsoon. In the more open system of Baguala Bay, productivity was distributed throughout the year (Table 4). Upwelling into Ambon Bay occurs from March to August (Wyrtki 1961). Thus it might be expected that maximum zooplankton numbers would occur in September, after the water column has stabilized, but while productivity was still boosted by the effect of the upwelling. This was the case in the survey of Sutomo (1984), who sampled the zooplankton of the Inner Bay at monthly intervals from February 1983 to March 1984. He recorded the peak of zooplankton in September 1983, reaching a density of 1,910,387 individuals/1,000m^3. This is consistent with the findings of the present study, in which zooplankton densities increased during the upwelling period, reaching 338,490 individuals/m^3 in August in the transition region.

Table 4. The abundance of copepods (Ind./m^3) at 7 stations throughout Baguala Bay, January–March and May–September 1993.

Month	Stations						
	1	2	3	4	5	6	7
January	560	1,477	1,195	1,220	503	1,364	1,182
February	815	3,766	2,779	3,535	4,788	2,936	3,921
March	1,359	1,457	2,461	2,785	5,845	4,769	4,002
May	1,374	2,892	3,904	4,050	4,096	10,716	4,049
June	1,847	7,537	2,201	4,057	1,115	2,332	4,097
July	1,497	2,316	2,106	1,598	4,307	4,822	10,075
August	470	2,350	1,081	5,148	1,092	4,575	2,830
September	2,435	3,421	2,788	5,204	3,869	3,081	10,275

Throughout the study, there was a tendency for the stations in the transition region to have the most diverse communities. This was to a large extent the result of the higher species richness associated with the presence of both inshore species (those never recorded from the Outer Bay) and offshore species (those never recorded from the Inner Bay).

During the early part of the study, zooplankton densities in the Outer Bay and transition region were comparable to but higher than those in the Inner Bay. In August, at the end of the upwelling period, densities in the Inner Bay increased. Nevertheless, this part of the Bay remained the least rich region, being comparable to densities in the Outer Bay, while densities of zooplankton in the transition region increased dramatically. It seems likely that the upwelling induced considerable mixing of Outer Bay and transition region waters, leading to similar levels of productivity and communities in June and July.

Calanus, Paracalanus, Oikopleura, Oithona, Sagitta, Corycaeus, and various meroplankton were distributed throughout the sampling area. It is possible to identify an inshore component to the plankton. Thus, *Penilia, Pleurpis, Podon, Tintinopsis,* and Cirripedia, hydrozoan, and fish larvae were all recorded from the Inner Bay and transition region only. Similarly, an offshore component consisting of *Rhincalanus, Euchaeta, Salpa, Cereis, Thalia, Hyperia, Centropages, Doliolum, Lingula,* and *Candacia* were only recorded from the transition region and Outer Bay. In general, meroplankton were considerably more numerous in the Inner Bay and transition than in the Outer Bay (Table 3). This supports the view that there exist two distinct faunal communities, which mix to a greater or lesser extent in the transition region.

The classic pattern of zooplankton production in tropical regions is a series of small, essentially random, deviations from the long-term mean (Raymont 1984). This study has shown considerable spatial and temporal variability in the coastal zooplankton of Pulau Ambon. The patterns in Baguala Bay are probably a function of upwelling-driven productivity, advection of offshore/deepwater species, and small-scale local variation driven by freshwater inputs (with associated nutrients, turbidity, and decreased salinity). In Ambon Bay, the situation is more clearly related to the hydrography of the Bay, the mixing of the inshore and oceanic faunas maximizing biodiversity in the transitional region of Ambon City.

The overall species richness of the two bays is markedly different. Both receive upwelled water, and "deepwater" indicator species have been recorded in the outer regions of both. The lower species richness of Ambon Bay may be due to the relatively greater inputs of freshwater, or may arise out of the slightly different survey methods (unlikely). Or they may be a function of the lowered water quality in this region due to the large inputs of industrial and urban wastewater from Ambon City. More work is required to investigate this further.

5. Summary

Spatial and temporal patterns in the biodiversity of Ambon and Baguala Bays are described. Both regions receive seasonal inputs of nutrient-rich deepwater and associated oceanic plankton. Species richness was greatest in the transition between coastal and oceanic regions in Ambon Bay, but overall diversity was higher in Baguala Bay. This may be the result of the lowering of water quality in Ambon Bay due to pollution impacts.

6. Acknowledgements

The authors gratefully acknowledge the British Council, without whose support of exchange visits the authors would have never met or carried out this work. Thanks also to the various field assistants, in particular Ellen; Dr. S. M. Evans, who provided facilities at the Dove Marine Laboratory for the processing of samples; and Carol Weiss for typing the manuscript.

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Fig 1. Sampling locations around Pulau Ambon and the location of Ambon in Indonesia (inset).

Figure 2. Zooplankton species richness as determined by net hauls at stations in outer (solid blocks) and inner (open blocks) Ambon Bay, and the transition zone (hatched blocks) during June–August 1990. (See text for explanation of the zones.)

Figure 3. Nonmetric Multi-Dimensional Scaling (MDS) ordinations of species abundance patterns for the Ambon Bay stations in: (a) June, (b) July, and (c) August 1990 (● Inner Bay, ▲ Transition zone, and ■ Outer Bay).

(a) June

(b) July

(c) August

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